CHAPTER 1
INTRODUCTION

1.1 Purpose

The purpose of this technical manual is provide facility managers with the information and procedures necessary to baseline the reliability and availability of their facilities, identify "weak links", and to implement cost-effective means of improving reliability and availability.

1.2 Scope

The information in this manual reflects both the move to incorporate commercial practices and the lessons learned over many years of acquiring weapon systems "by the book." It specifically focuses on the availability of electrical and mechanical systems for command, control, communications, computer, intelligence, surveillance and reconnaissance (C4ISR) facilities and the role reliability plays in determining availability. The manual, in the spirit of the new policies regarding acquisition, describes the objectives of a sound strategy and the tools available to meet these objectives.

1-3. References

Appendix A contains a complete listing of references used in this manual.

1-4. Definitions (Special Terms)

The three key terms used in this TM are availability, reliability, and maintainability. Additional terms and abbreviations used in this manual are explained in the glossary.

  a. Availability. Availability is defined as the percentage of time that a system is available to perform its function(s). It is measured in a variety of ways, including Uptime/Uptime + Downtime (Total Time) and MTBF/MTBF+MTTR. Chapter 2 has a detailed discussion of availability.

  b. Reliability. Reliability is concerned with the probability and frequency of failures (or more correctly, the lack of failures). A commonly used measure of reliability for repairable systems is the mean time between failures (MTBF). The equivalent measure for non-repairable items is mean time to failure (MTTF). Reliability is more accurately expressed as a probability over a given duration of time, cycles, etc. For example, the reliability of a power plant might be stated as 95% probability of no failure over a 1000-hour operating period while generating a certain level of power. Reliability is usually defined in two ways as shown in the following definitions. (Note that the electrical power industry has historically not used the definitions given here for reliability. The industry defines reliability as the percentage of time that a system is available to perform its function; i.e., availability. The relationship between reliability and availability is discussed in paragraph 1-6.)

    (1) The duration or probability of failure-free performance under stated conditions.

    (2) The probability that an item can perform its intended function for a specified interval under stated conditions. (For non-redundant items this is equivalent to the preceding definition (1). For redundant items this is equivalent to definition of mission reliability.)

c. Maintainability. Maintainability is defined as the measure of the ability of an item to be retained in or restored to a specified condition when maintenance is performed by personnel having specified skill levels, using prescribed procedures and resources, at each prescribed level of maintenance and repair. Simply stated, maintainability is a measure of how quickly and economically failures can be prevented through preventive maintenance or system operation can be restored following a failure through corrective maintenance. A commonly used measure of maintainability in terms of corrective maintenance is the mean time to repair (MTTR). Note that maintainability is not the same as maintenance. Maintainability is a design parameter, while maintenance consists of actions to correct or prevent a failure event.

1-5. Historical perspective

In measuring the performance of electrical and mechanical systems for C4ISR facilities, availability is of critical concern. The level of availability achieved in operation is determined by many factors, but arguably the two most important factors are reliability and maintainability. Reliability and maintainability (R&M) are two disciplines that have increased in importance over the past 30 years as systems have become more complex, support costs have increased, and defense budgets have decreased. Both disciplines, however, have been developing for much longer than 30 years.

a. Reliability. Reliability, for example, has been a recognized performance factor for at least 50 years. During World War II, the V-1 missile team, led by Dr. Wernher von Braun, developed what was probably the first reliability model. The model was based on a theory advanced by Eric Pieruschka that if the probability of survival of an element is $1/x$, then the probability that a set of n identical elements will survive is $(1/x)^n$. The formula derived from this theory is sometimes called Lusser's law (Robert Lusser is considered a pioneer of reliability) but is more frequently known as the formula for the reliability of a series system: $R_S = R_1 \times R_2 \times \ldots \times R_n$.

b. Maintainability. Maintainability is perhaps less fully developed as a technical discipline than is reliability. Maintainability is a measure of the relative ease and economy of time and resources with which maintenance can be performed. Maintainability is a function of design features, such as access, interchangeability, standardization, and modularity. Maintainability includes designing with the human element of the system in mind. The human element includes operators and maintenance personnel.

1-6. Relationship among reliability, maintainability, and availability

Perfect reliability (i.e., no failures, ever, during the life of the system) is difficult to achieve. Even when a "good" level of reliability is achieved, some failures are expected. The effects of failures on the availability and support costs of repairable systems can be minimized with a "good" level of *maintainability*. A system that is highly maintainable can be restored to full operation in a minimum of time with a minimum expenditure of resources.

a. Inherent availability. When only reliability and corrective maintenance or repair (i.e., design) effects are considered, we are dealing with *inherent availability*. This level of availability is solely a function of the inherent design characteristics of the system.

b. Operational availability. Availability is determined not only by reliability and repair, but also by other factors related to preventative maintenance and logistics. When these effects of preventative maintenance and logistics are included, we are dealing with *operational availability*. Operational availability is a "real-world" measure of availability and accounts for delays such as those incurred when

spares or maintenance personnel are not immediately at hand to support maintenance. Availability is discussed in more detail in chapter 2.

1-7. The importance of availability and reliability to C4ISR facilities

C4ISR facilities support a variety of missions. Often these missions are critical and any downtime is costly, in terms of economic penalties, loss of mission, or injury or death to personnel. For that reason, availability is of paramount importance to C4ISR facilities.

   a. Availability. Availability of a system in actual field operations is determined by the following.

   (1) The frequency of occurrence of failures. These failures may prevent the system from performing its function (mission failures) or cause a degraded system effect. This frequency is determined by the system's level of reliability.

   (2) The time required to restore operations following an system failure or the time required to perform maintenance to prevent a failure.   These times are determined in part by the system's level of maintainability.

   (3) The logistics provided to support maintenance of the system. The number and availability of spares, maintenance personnel, and other logistics resources combined with the system's level of maintainability determine the total downtime following a system failure.

   b. Reliability. Reliability is a measure of a system's performance that affects availability, mission accomplishment, and operating and support (O&S) costs. Too often we think of performance only in terms of voltage, capacity, power, and other "normal" measures. However, if a system fails so often (i.e., poor reliability) that it's always being repaired, voltage, capacity, power, and capacity are irrelevant.

   c. Reliability, trust, and safety. The importance of reliability is evident in our daily lives. When we begin a road trip in the family automobile, we do so with the assumption that the car will not break down. We are, perhaps unconsciously, assuming that the car has an inherent level of reliability. Similarly, we have a certain level of trust that the airliners in which we fly, the elevators we ride, and the appliances we purchase for our home will operate with little chance of failure. In dealing with systems and systems where failure can result in injury or death, the distinction between reliability and safety becomes blurred. Reliability does indeed affect safety, although safety is primarily concerned with preventing injury while reliability is primarily concerned with ensuring that a system does not fail to perform its function. While related and complementary, these two objectives are not identical.

   d. Reliability and costs. Reliability also affects the costs to own and operate a system. Again using the example of the family automobile, the cost of ownership includes gas and oil, insurance, repairs, and replacement of tires and other "expendables." Reliability determines how often repairs are needed. The less often the car has a failure, the less it will cost to operate over its life. The reliability of any repairable system is a significant factor in determining the long-term costs to operate and support the system. For non-repairable systems, the cost of failure is the loss of the function (e.g., the missile misses its target, the fuse fails to protect a circuit, etc.).

   e. The inevitability of failures. Regardless of how reliable a system may be, some failures will occur. An effective maintenance program applied to a system that has been designed to be maintainable is necessary to deal with the certainty of failure. For example, even when several redundant items are

installed to decrease the chance of a mission failure, when any one item fails, it must be repaired or replaced to retain the intended level of redundancy.

1-8. Improving availability of C4ISR facilities

The decision on which methods to use for improving availability depends on whether the facility is being designed and developed or is already in use.

  a. Existing C4ISR facilities. For a facility that is being operated, two basic methods are available for improving availability when the current level of availability is unacceptable: (1) selectively adding redundant units (e.g., generators, chillers, fuel supply, etc.) to eliminate sources of single-point failure, and (2) optimizing maintenance using a reliability-centered maintenance (RCM) approach to minimize downtime. Of course, some combination of these two methods can also be implemented. The two methods will be discussed in more detail in chapter 3. A third method is available but is very expensive for existing facilities. That method is to redesign subsystems or to replace components and subsystems with higher reliability items. This method will be discussed in paragraph 1-8b, New C4ISR Facilities.

  b. New C4ISR facilities. The opportunity for designing for high availability and reliability is greatest when designing a new facility. By applying an effective reliability strategy, designing for maintainability, and ensuring that manufacturing and commissioning do not negatively affect the inherent levels of reliability and maintainability, a highly available facility will result. Although the primary focus of this TM is on improving the availability of current facilities, a brief discussion of the approach used when designing a new facility is provided to give the reader an appreciation of an effective design and development program.

  (1) A reliability strategy describes how an organization approaches reliability for all systems and services it develops and provides to its customers. The strategy can be considered as the basic formula for success, applicable across all types of systems and services. A reliability strategy that has proved successful in a variety of industries and in government is shown in figure 1-1.

  (2) A reliability program is the application of the reliability strategy to a specific system or process. As can be inferred from figure 1-1, each step in the strategy requires the selection and use of specific methods and tools. For example, various methods can be used to develop requirements or evaluating potential failures.

  (a) Developing Requirements. Translations, and analytical models can be used to derive requirements. Quality Function Deployment (QFD) is a technique for deriving more detailed, lower-level requirements from one level of indenture to another, beginning with customer needs. It was developed originally as part of the Total Quality Management movement. Translations are parametric models intended to derive design values of reliability from operational values and vice versa. Analytical methods include thermal analysis, durability analysis, predictions, etc.
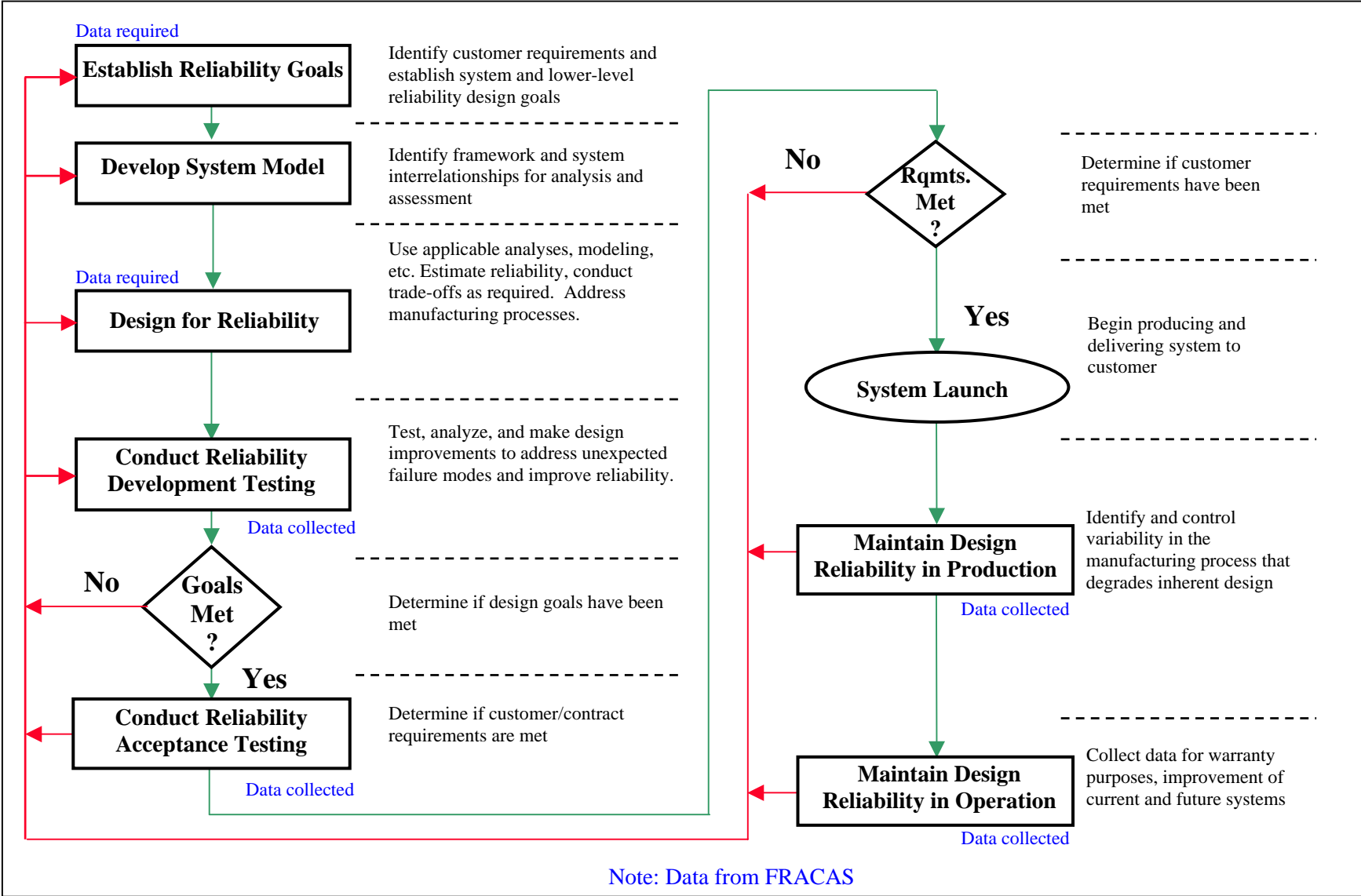
Data required

Establish Reliability Goals

Identify customer requirements and establish system and lower-level reliability design goals

Develop System Model

Identify framework and system interrelationships for analysis and assessment

Data required

Design for Reliability

Use applicable analyses, modeling, etc. Estimate reliability, conduct trade-offs as required. Address manufacturing processes.

Conduct Reliability Development Testing

Test, analyze, and make design improvements to address unexpected failure modes and improve reliability.

Data collected

No   **Goals Met ?**

Determine if design goals have been met

Yes

Conduct Reliability Acceptance Testing

Determine if customer/contract requirements are met

Data collected

No   **Rqmts. Met ?**

Determine if customer requirements have been met

Yes

Begin producing and delivering system to customer

System Launch

Maintain Design Reliability in Production

Identify and control variability in the manufacturing process that degrades inherent design

Data collected

Maintain Design Reliability in Operation

Collect data for warranty purposes, improvement of current and future systems

Data collected

Note: Data from FRACAS

Figure 1-1. A sound reliability strategy addresses all phases of a system's life cycle.

(b) Evaluate possible failures. Failure Modes and Effects Analysis (FMEA) and Fault Tree Analysis (FTA) are two different methods for evaluating possible failures. The reliability engineer must determine which one to use, or whether to use both. Chapter 3 will address these and other methods and how to determine which are applicable to a specific situation. Selecting the specific tasks to accomplish each step of the strategy results in a tailored system program. Table 1-1 shows some of the factors that must be considered in selecting tasks to implement the reliability strategy.

Table 1-1. Factors in selecting tasks for a specific program

Effectiveness and applicability of tasks vary depending on:

- Production runs (total population) – limits use of system-level statistical analysis
- Critical functions/cost of failure – may require exhaustive analysis
- Technology being used – may require new models
- Nature of development (i.e., evolutionary vs. revolutionary) – experience of much less value when breaking new ground

Selection of tasks is also a function of past experience, budget, schedule, and amount of risk you are willing to accept

(3) The entire effort of designing for reliability begins with identifying the customer's reliability requirements. These requirements are stated in a variety of ways, depending on the customer and the specific system. Table 1-2 lists some of the ways in which a variety of industries measure reliability. Note that in the case of the oil & gas and communications industries, availability is the real requirement. The reliability and maintainability requirements must then be derived based on the availability requirement.

Table 1-2. Typical reliability-related measures

Customer	System	Measure of Reliability
Airline	Aircraft	On-time departure
Consumer	Automobile	Frequency of repair
Hospital	Medical	Availability & Accuracy
Military	Weapon	Mission Success Probability
Highway Department	Bridge	Service Life
Oil & Gas	Subsea	Availability
Communications Organization	Utilities	Availability